REP 1995-058

Vol. 36 (1/2)
International Biodeterioration & Biodegradation (1995) 51-64
Published by Elsevier Science Limited
Printed in Great Britain
0964-8305/95 $9.50 + 0.00

ELSEVIER

0964-8305(95)00058-5

Mortality of Gallinaceous Birds Associated with 2% Zinc Phosphide Baits for Control of Voles in Alfalfa

C. A. Ramey & R. T. Sterner

US Department of Agriculture, Animal and Plant Health Inspection Service,
Denver Wildlife Research Center, P.O. Box 25266, Bldg 16, Denver Federal Center,
Denver, CO 80225, USA

ABSTRACT

Nontarget hazards to 52 ring-necked pheasants and 51 California quail were studied using 2·0% zinc phosphide (Zn_3P_2) steam-rolled-oat (SRO) baits to control gray-tailed voles in 12 (0·2-ha) enclosures planted in alfalfa. Pen raised birds were wing-clipped and 25–26 of each species were randomly assigned to three Zn_3P_2 baited or three control baited enclosures (eight or nine birds and 23–24 voles in each). Twenty-four birds of each species were also monitored twice daily using radiotelemetry. Following acclimation and pre-baiting (7 days), 2·0% Zn_3P_2 or control (0·0% Zn_3P_2) bait was broadcast by mechanical spreaders, and birds were observed or monitored for 14 days post-baiting. Zinc phosphide deaths, supported by necropsy results, occurred in 69% (18/26) of the pheasants, and none (0/26) of the quail. Other bird deaths were associated with six predator attacks, four accidents, and three escapes. Eight birds were missing at the completion of the study. These losses were not significantly different between species, baiting groups, and radiocollar status. The occurrence of all but one Zn_3P_2 death (17/18) within 24 h of exposure was highly significant ($p < 0·00001$) vs mortality observed pre-baiting and >1 day post-baiting. Sublethal toxic effects of Zn_3P_2 were observed in two pheasants. Postulated attributes of the efficacious bait (> 94% mortality for voles) that may have decreased nontarget exposure and environmental risks (particularly to quail) are discussed. Plans for research to assess the potential hazard of Zn_3P_2 to wild, free-ranging pheasants following a typical vole control program in alfalfa are underway.

INTRODUCTION

Zinc phosphide (Zn_3P_2) is an acute vertebrate pesticide (Hood, 1972; Gratz, 1973). Its mode of action is attributed to the release of phosphine gas (PH_3) during hydrolysis in the gastrointestinal (GI) tract of poisoned animals (Henderson & Boggess, 1979). Death in rodents typically occurs in <120 h and results from cessation of respiration induced by PH_3 (Andreev *et al.*, 1959; Chefurka *et al.*, 1976). Over 60 acute toxicity studies have been conducted on birds and mammals (Johnson & Fagerstone, 1994). Of the avian species tested, waterfowl (Glahn & Lamper, 1983) and gallinaceous birds such as pheasants (Hayne, 1951) are very sensitive. The California Department of Fish and Game (CDFG) has suggested that Zn_3P_2 use in California may impact nontarget wildlife including quail and pheasants, but the actual effect is unknown (CDFG, 1962; Littrell, 1990). Secondary poisoning with Zn_3P_2 has not been an issue, because it is not accumulated in muscle tissue and decomposes rapidly in the GI tract of poisoned animals (Savarie, 1981; Johnson & Fagerstone, 1994). In the environment, Zn_3P_2 breaks down when exposed to wet conditions (Zbirovsky & Myska, 1957), and its toxicity decreases (Hayne, 1951; Hilton *et al.*, 1972).

Zinc phosphide (CAS no. 1314-84-7) is a relatively broad spectrum rodenticide that has a variety of agricultural uses including the control of jackrabbits and prairie dogs on rangeland (Evans *et al.*, 1970; Tietjen & Matschke, 1982), nutria in agricultural areas (Evans *et al.*, 1966) rats in sugarcane (Doty, 1945; Hilton *et al.*, 1972; Pank, 1976) and macadamia nuts (Fellows *et al.*, 1978), and voles in orchards (Hegdal & Gatz, 1977). Voles also cause extensive damage to agricultural crops in the western US (Marsh, 1988), including alfalfa (Lewis & O'Brien, 1990) with an estimated \$8·5 million annual loss in alfalfa production in California (Clark, personal communication 1993). Zn_3P_2 is being considered for reregistration by the Environmental Protection Agency (EPA) under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) as amended (FIFRA, 1988; Ramey *et al.*, 1994). In anticipation of EPAs reregistration requirements, the California Department of Food and Agriculture (CDFA) has sought efficacy and nontarget data for their label [Rodent bait zinc phosphide treated grain (2·00%), EPA Reg. no. CA890027].

The CDFA 2% Zn_3P_2-treated grain bait is manufactured as steam-rolled-oat (SRO) groats and is broadcast to control California Voles (*Microtus californicus*) and Montane Voles (*M. montanus*) in alfalfa (*Medicago sativa*). Label specifications state that a single broadcast application of 5·6–11·2 kg/ha (5–10 lb/acres) of this bait following one recommended pre-baiting to enhance bait acceptance by voles is effective for reducing vole populations in alfalfa prior to fall harvests or during the dormant season. However, bait is not to be applied within 30 days of harvest. The objective of the current study was to determine the potential nontarget hazards to ring-necked pheasants (*Phasianus colchicus*) and California quail (*Callipepla californica*) when applying CDFAs 2·0% Zn_3P_2-treated bait, according to label directions, to control gray-tailed voles in alfalfa [using 0·2 ha (0·5 acres) enclosures]. Sterner *et al.* (1994) in a joint study to the nontarget hazards reported here, calculated the efficacy for mechanical broadcasting of 2·0% Zn_3P_2 SRO baits to control voles within the 0·2 ha enclosures was >94%.

METHODS AND MATERIALS

Study site

The Hyslop Crop Science Field Laboratory (Hyslop Farm) study site at Oregon State University (OSU) is located approximately 10 km north of Corvallis, Oregon and within the range of the ring-necked pheasant and California quail. The flora, fauna and climate at Hyslop Farm are believed to be similar to the conditions for pesticide use in California. Hyslop Farm is situated in the Willamette Valley ~60 km east of the Pacific Ocean on the leeward side of the Coastal Range (longitude 123°12′W; latitude 44°38′N). The topography is generally level (elevation ~70 m or ~230 ft), and it is composed of a woodburn silty-clay loam soil (pH = 6·0). It has a mild climate characterized by arid summers and wet the remainder of the year. During the study (9/25/93–10/15/93), mean (± SD) maximum and minimum air temperatures were 24·4°C (± 5·0°) and 7·5°C (± 2·4°), respectively; precipitation totalled 1·83 cm (0·72 in).

Hyslop Farm is a ~80 ha research facility, operated by OSU's Department of Fisheries and Wildlife (Edge & Wolff, 1993). Within Hyslop Farm 24, 0·2 ha (0·5 acres) enclosures are located that have been constructed of galvanized sheet metal ~1 m high and buried 0·6 m deep. Adjacent panels are joined to form a continuous barrier to reduce rodent burrowing. Each enclosure (~ 45 × 45 m) was planted with alfalfa in the summer of 1991. A 1-m wide strip along the inside of the fence was not planted with alfalfa and remained bare ground to minimize usage by voles and to reduce escapes. Because the OSU enclosures had been used in the development of improved ecological risk-assessment techniques for insecticides (Bennett *et al.*, 1995), half of the alfalfa enclosures had been mowed once or twice during each subsequent growing seasons and the others had not. Mean alfalfa height was 38·4 cm (15·1 in) in mowed enclosures and 36·2 cm

(14·3 in) in non-mowed enclosures. Design precautions were taken to control for possible biases in the enclosure environment related to alfalfa height or the continued presence of Guthion 2S (azinphos-methyl), the insecticide used in the previous study. Statistical analyses showed no significant differences in alfalfa height among the enclosures and the foliage/soil were free from detectable Guthion 2S treatment residues (Edge & Manning, 1994; Sterner *et al.*, 1994).

Procedures for voles, pheasants and quail

In order to approximate a real-world vole control program, we established a density goal of ~125 voles/ha (Marsh, personal communication, 1993). We were able to stock 23–24 voles in each 0·2 ha enclosure, with roughly proportionate numbers of males and females. Additional details of the vole efficacy study are in Sterner *et al.* (1994).

Pen reared ring-necked pheasants and California quail were obtained from a commercial supplier, wing-clipped and banded. Pheasants weighed >440 g each with a sex ratio of seven roosters and 45 hens; California quail weighed >125 g each with 44 roosters and seven hens. All birds were considered adults (>20 weeks), and all the quail and many of the pheasants were hatched in the spring of 1993. Birds corresponded in age to adults-of-the-year which Hayne (1951) believed comprised the largest cohort in wild populations in the fall of the year. Therefore, we believe our predominant use of adults-of-the-year should most accurately reflect the most appropriate age cohort for determining the nontarget hazard to pheasants and quail from the fall pre-harvest application of Zn_3P_2 to control voles.

The research timeline for this study was comprised of three successive periods (Fig. 1). These were: (1) 7-day transportation, acclimation, and pre-bait exposure period (23 September to < 3 p.m. 30 September); (2) baiting day and first 24 h bait exposure period (⩾ 3 p.m. 30 September to < 3 p.m. 1 October); and (3) 13-day bait exposure period and pheasant and quail trap-out (⩾ 3 p.m. 1 October to 14 October). Following transportation to Hyslop Farm on 23 September, 1993, the birds were weighed, sexed and radio-equipped (discussed below) on 23–24 September. The pheasants and quail were released following weight randomization to their respective 0·2 ha enclosures on 25 September. Following the advice of game bird breeders (Koepp, personal communication, 1993), natural group numbers were established in each enclosure with eight to nine quail of mixed sexes or eight to nine pheasants with one or two roosters. Enclosure alfalfa provided cover, shelter and a variety of insects for the birds. Purina Game Bird Flight Conditioner and water were also provided

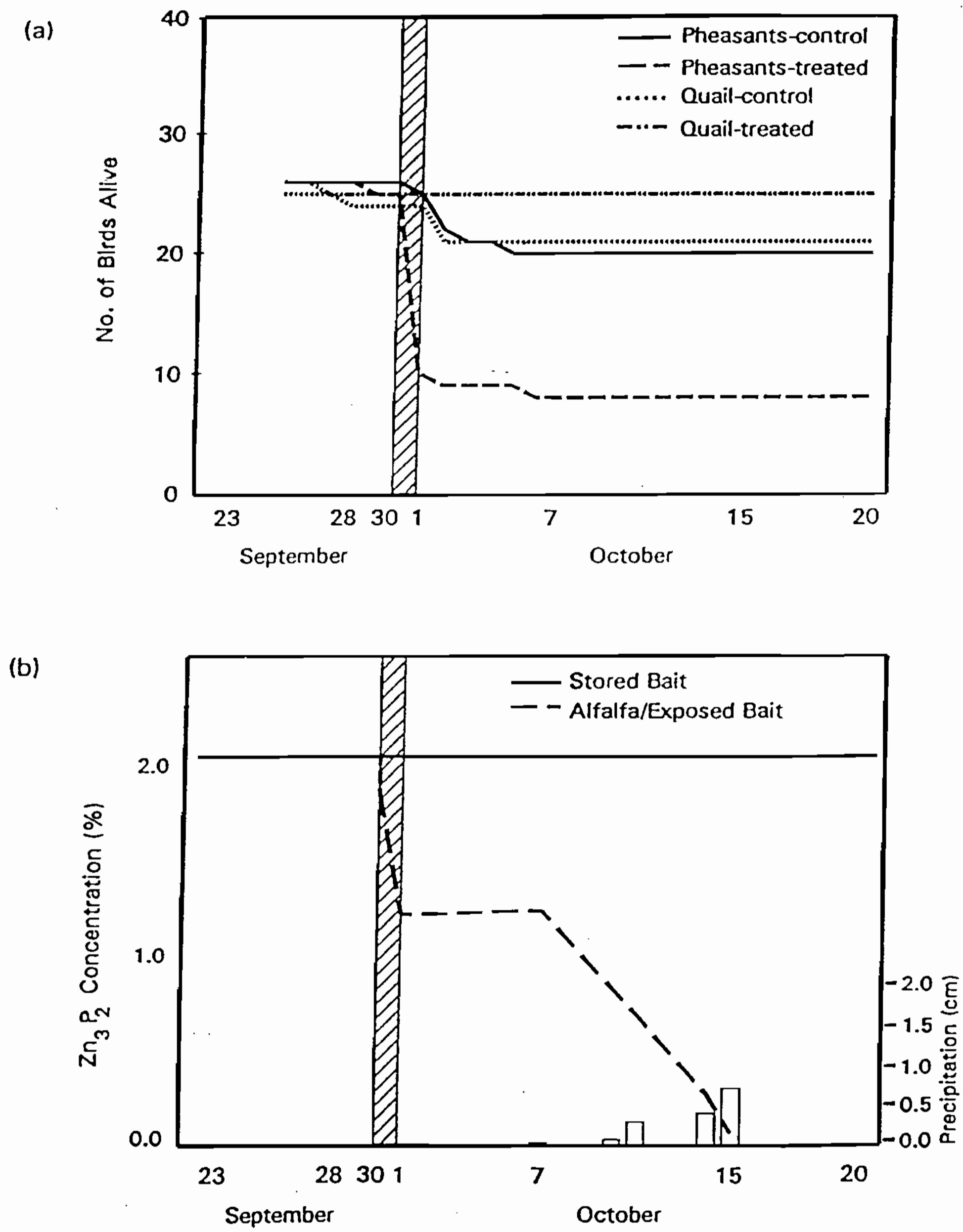

Fig. 1. Schematic diagram of the research timeline indicating the baiting day and first 24 h bait exposure period ($\geqslant$ 3 p.m. 30 September to $<$ 3 p.m. 1 October, 1993): (a) illustrates the pheasant and quail mortality; and (b) demonstrates the deterioration of the Zn_3P_2 baits in the field in relation to precipitation.

ad libitum to simulate a natural environment that would contain alternative food.

Because the walled enclosures did not have covering nets or wires, the activities of predators that might have had an impact on the study animals (i.e. voles, pheasants and quail) and predation deaths were documented. A total of 109 h of diurnal raptor observations were recorded daily from 27 to 30 September, 1993 (~6:30 a.m.–19:00 p.m.) and intermittently thereafter through 15 October, 1993, because of the observed minimal impact of predators on the study. Observations were made using a spotting scope from an unobstructed observation platform on the east side of the enclosures, ~3 m above ground level. Habitat for predatory avian and mammal species included: (1) a large hay barn located ~ 200 m SW of the study site; (2) a row of blackberry (*Rubus* spp.) bushes at a minimum distance of ~100 m north of the study site; and (3) a large roost tree located ~130 m NW of the site.

Twenty-four ring-necked pheasants (six males and 18 females) and 24 California quail (six females and 18 males) were equipped with radio-transmitters from a commercial source (Holohil Systems Ltd). The ratio of transmitter weight to body weight was <1% for pheasants and <3% for quail. The pheasant transmitters were made for tail clip/glue mounts, but because many of the pheasants were molting the transmitters were modified to use an elastic collar slipped over the head. These transmitters had a battery life of 3 months, and ranged in frequency from 164·437 to 167·013 MHz. Transmitters built for California quail had a minimum battery life of 5 weeks, ranged in frequency from 164·4375 to 167·0125, and were built with elastic attachment neck collars. Transmitters were assigned from four bands each with 12 channels so as to minimize signal confusion between enclosures. Following release, the location of each bird was determined from the roadway berms adjacent to the enclosures with ground tracking vehicles equipped with truck-mounted dual antennas and a peak/null box following the general procedures of Dodge (1967) and Hegdal and Colvin (1986). General locations and movements were recorded twice daily, morning and evenings. Transmitter equipped birds that escaped the enclosures were recaptured using portable telemetry receivers and a hand-held three-element yagi antenna, checked for condition, and wing-clipped (if appropriate), before being returned to their assigned enclosure. Escapes were recorded, noting the condition of the bird. If no bird movements were observed, moribund or dead birds were located using the procedures of Mech (1983) with portable receivers and hand-held antennas. Sublethal effects of Zn_3P_2 poisoning were recorded as described by Janda and Bosseova (1970) and Hudson *et al.* (1984).

Zinc phosphide baits and broadcasting procedures

Prior to bait formulation on 10 September, 1993, the technical Zn_3P_2 was assayed by the Analytical Chemistry Section (ACS) at the Denver Wildlife Research Center (DWRC) using Analytical Method 11-B at 88·8 ± 0·27% (SD). Control and Zn_3P_2 SRO baits were prepared at DWRC according to the Confidential Statement of Formula (CSF). All baits were dyed black.

Baits were received at Hyslop Farm by a Certified Pesticide Applicator (CPA) and stored in the Pesticide Storage Facility (PSF). Additional details including broadcast pattern and calibration proficiency calculations are presented by Sterner *et al.* (1994). CPAs were told to avoid baiting the outermost ~2-m-wide borders of the alfalfa enclosures to reduce the chances of pheasants/quail foraging on baits in areas of bare ground (~1-m-wide no-plant border next to the enclosure walls on all four sides).

On 28 September, 1993 (~16:00–18:00 h), voles were pre-baited using label recommendations with an application rate of 11·2 kg/ha (10 lb/acre) of control bait (0·0% Zn_3P_2 SRO groats) adjusted for the ~1-m-wide zone of no alfalfa adjacent to enclosure walls. After the bait was well accepted by the voles (Sterner *et al.*, 1994), control or 2·0% Zn_3P_2 SRO groats were broadcast into the appropriate randomly selected enclosures each on 30 September (~15:00–18:00 h). Procedures and application rates remained the same as during pre-baiting. Zn_3P_2 baits were available to the voles and birds from late afternoon on 30 September (~ 3 p.m.) until 14 or 15 October when all surviving birds were recaptured, euthanatized with CO_2 according to American Veterinary Medicine Association (AVMA) guidelines (AVMA, 1993), and necropsied. Zinc phosphide mortality was determined upon necropsy by the identification and enumeration of SRO groats in the GI tracts (mainly crops) of dead birds and the smell of phosphine gas.

Batch samples of control and test baits were collected from the storage bags at the time of preparation, bait application, and upon their return to DWRC. They were analyzed to determine the Zn_3P_2 concentration and stability of the baits throughout the study. All bait samples were analyzed by the ACS staff at DWRC using a PH_3 headspace analysis technique (DWRC Analytical Method 29-A). A 30% sulfuric acid solution was used to hydrolyze Zn_3P_2 during shaking; head gas samples of PH_3 were then injected into a HP 5880 GC with HP flame photometric detector. Because of the Study Director's interest in the weatherability of CDFAs Zn_3P_2 bait and the possibility of relating the time of nontarget deaths with the changing Zn_3P_2 bait concentrations, a separate environmental deterioration study was conducted in an adjacent alfalfa field at Hyslop Farm and excerpts are reported below (Sterner & Ramey, 1995).

RESULTS AND DISCUSSION

Pheasant and quail mortality and survival

None of the California quail (0/26) died of Zn_3P_2 poisoning as confirmed by necropsy; whereas 62% of ring-necked pheasants (16/26) residing in baited enclosures died by ingesting the 2·0% Zn_3P_2 bait (Fig. 1). Ninety-four percent of the mortalities from Zn_3P_2 poisoning occurred within 24 h of bait application. Analysis of the survival ratios between control baited and 2·0% Zn_3P_2 baited pheasants was significantly different [Fisher's Exact Test (SAS Inst., 1987), $p < 0{\cdot}01$], indicating the hazard to ring-necked pheasants in this enclosure study was significant. In addition, two pheasants from control enclosures escaped to 2% Zn_3P_2 baited enclosures and died. The 18 zinc phosphide poisoned pheasants had an average of 180 (SD $\pm$ 93) Zn_3P_2 SRO groats in their crops. Control birds were similarly examined at the completion of the study, and none had evidence of consuming the control bait. No observations of lethal intoxication in live birds were observed in this study. Pheasants died during the first night following baiting in generally dense vegetation, and they showed no signs of a struggle.

Diverse LD_{50} values have been reported for ring-necked pheasants and examples include: 8·8 mg/kg (CDFG, 1962), 9 mg/kg (Hayne, 1951), 16·4 mg/kg (Hudson *et al.*, 1984), and 26·7 mg/kg of Zn_3P_2 (Janda & Bosseova, 1970). The Zn_3P_2 LD_{50} dose for California quail is reported as 13·5 mg/kg (CDFG, 1962). In this study, based on the average weight (~23 mg) of each SRO groat and assuming a 2% uniform formulation of Zn_3P_2 on each groat, we estimated that 0·46 mg of Zn_3P_2 should be present per SRO groat. Therefore, young ring-necked pheasants weighing about 500 g would need to ingest from 10 to 29 Zn_3P_2-treated SRO groats to attain the LD_{50} values (8·8 and 26·7 mg/kg of Zn_3P_2) reported above. The average consumption of 180 Zn_3P_2 baits by each dead pheasant suggests that it ate from 6 to 20 times its LD_{50} dose on average. Although the California quail (100 g) needed to ingest fewer SRO groats (~4 Zn_3P_2-treated baits) to attain its LD_{50} value of 13·5 mg/kg; none of them died from Zn_3P_2 poisoning.

Hines and Dimmick (1970) reported that bobwhite quail were repelled by black-dyed, whole Zn_3P_2-treated oat groats in laboratory trials under conditions of free choice of bait. They concluded that black-dyed, whole Zn_3P_2-treated oat groats posed relatively low hazard to bobwhite quail if the baits were distributed at recommended rates during a period of reasonable food abundance. Over the years a number of other dyes have been tried so as to decrease the nontarget hazard of Zn_3P_2 grain baits to other gallinaceous birds, but they have not been successful. Hayne (1951) reported that methyl green-dyed corn was not a deterrent to consumption by pheasants, and Janda and Bosseova (1970) found that neither Zn_3P_2 or red dye prevented pheasants and partridges from consuming grain baits.

Mortality associated with other factors [predators (6%), accidents (3%), escapes (3%), and sickness (1%)] was not significantly different between avian species, baited groups, or presence of radiocollars [Fisher's Exact Test (SAS Inst., 1987) all $p > 0{\cdot}40$] (Fig. 1). One coyote (*Canis latrans*) was observed on Hyslop Farm, but not in the enclosures. Tracks were recorded for other predators including red fox (*Vulpes vulpes*), striped skunk (*Mephitis mephitis*), and American raccoon (*Procyon lotor*). Diurnal raptor observations recorded the activities of barn owls (*Tyto alba*), great horned owls (*Bubo virginianus*), red-tailed hawks (*Buteo jamaicensis*), northern goshawks (*Accipiter gentilis*), northern harriers (*Circus cyaneus*), American kestrels (*Falco sparverius*), turkey vultures (*Cathartes aura*), crows (*Corvus brachyrhynchos*) and common ravens (*Corvus corax*). There were a total of 79 sightings predominantly of northern harriers, which resulted in five predation attempts in or near (<50 m) the enclosures, and two were successful — one vole was taken by a red-tailed hawk and one snake by a northern harrier. Two unsuccessful strikes were made by northern harriers on two California quail.

Six Zn_3P_2-baited pheasants survived to the end of the study. Four hens appeared normal on the first day post-baiting and daily thereafter, whereas two roosters showed sublethal signs of Zn_3P_2 poisoning. On the morning of 1 October (<24 h post-baiting), the roosters hid in heavy cover and seemed to be incapable of movement. They were easily approached and touched. They exhibited lethargy, hypoactivity and ataxia, Zn_3P_2 poisoning symptoms previously reported by Hudson *et al.* (1984). Remission was slow, and it was ~7 days before they began to move extensively. By ~14 days post-baiting, they appeared normal.

Zinc phosphide bait

The control and 2·0% Zn_3P_2 baits were accurately mixed and remained stable over the course of the study under storage conditions, dry and room temperature. While samples of control bait were always less than the Zn_3P_2 Method's Limit of Detection (<0·002% Zn_3P_2), Zn_3P_2 bait samples collected at the time of preparation (10–11 September), bait application (30 September), and study completion (20 October) were analyzed and had mean (± SD) nominal values of 2·0% (± 0·12%), 2·0% (±0·36%) and 2·0% (±0·10%) Zn_3P_2, respectively (Fig. 1). These results correspond closely with those of Elmore and Roth (1943) and Janda and Bosseova (1970), who reported no chemical loss of Zn_3P_2 on treated grains under conditions of storage. Sterner and Ramey (1995) have described the deterioration of the 2% (± 0·36) Zn_3P_2 SRO bait used in the current study as collected from the ground immediately after broadcast, and 1, 7 and 14 days later. Analyses of these samples yielded 1·80% (± 0·36%), 1·18%

($\pm$ 0·04), 1·20% ($\pm$ 0·11) and $\leqslant$ 0·26% ($\pm$ 0·05%) Zn_3P_2 (Fig. 1), respectively. The decrease of Zn_3P_2 concentration was ~10% immediately after broadcasting, an additional ~30% loss at 1 and 7 days (0·05 cm of rainfall on day 7), and an additional 47% loss by the end of the weathering study (14 October) following another 0·97 cm (0·38 in) of rainfall. Overall loss of Zn_3P_2 was $\geqslant$87% at 14 days post-baiting.

The initial 40% decrease in Zn_3P_2 concentration during the 24 h post exposure period was of particular interest because it coincided with the majority (17/18, >94%) of Zn_3P_2 pheasant deaths (Fig. 1). Chi-square analyses comparing survival proportions between control and 2·0% Zn_3P_2-baited enclosures (excluding missing birds) showed the first 24 h of exposure was very significantly different ($p < 0.00001$) using Fisher's Exact Test (SAS Inst., 1987) from pre-baiting survival ($p \cong 1.0$) and >1 day post-baiting survival ($p \cong 1.0$). Thus, the first 24 h post-application is the period of most potential risk to ring-necked pheasants.

Zinc phosphide bait deterioration has been a topic of discussion and research. Doty (1945) assumed that, because Zn_3P_2 breaks down under wet and/or acidic conditions, Zn_3P_2 baits should rapidly decompose under field conditions. Others have demonstrated the loss of Zn_3P_2 from their baits (particularly grain baits), and believe it is probably a function of several interacting factors including chemical decomposition (Hilton *et al.*, 1972), weathering (Elmore & Roth, 1943; Hayne, 1951; Hilton *et al.*, 1972; Breyl *et al.*, 1973; Koehler *et al.*, 1995), and soil acidity (Hilton *et al.*, 1972; Koehler *et al.*, 1995). Variable weatherability has been demonstrated by various scientists and seems to be related to rainfall and bait carrier interactions. Janda and Bosseova (1970) found no loss of Zn_3P_2 concentration with vaseline as a carrier; whereas Hayne (1951) reported a 2% per day decrease with vegetable oil. Hilton *et al.* (1972) found a 60% loss of Zn_3P_2 correlated with 2·54 cm of rain and a 3% corn oil carrier. Because of the reported differences in Zn_3P_2 bait deterioration associated with various carriers, Pank (1976) evaluated Zn_3P_2 losses from baits formulated with eight different adhesives. He found the most significant losses of Zn_3P_2 (~50%) occurred during the first 10 days of artificial weathering (i.e. one application of 3·8 cm of water) with a 3% lecithin oil carrier. We believe the lecithin oil (Alcolec-S) formulation used in this study reacted to rainfall in a similar way [i.e. $\geqslant$87% loss of Zn_3P_2 with 1·02 cm (0·40 in) of rain during 14 days]. Although the rate of deterioration of the Zn_3P_2 bait is important, even more important may be Hayne's (1951) observation that weathering accounted for some (~2%/day), but not all (~6%/day) of the loss of toxicity demonstrated in the bio-assays of weathered Zn_3P_2 bait.

An ideal zinc phosphide bait

We believe an ideal Zn_3P_2 bait to control voles in alfalfa should: (1) be efficacious; (2) be repellent to nontarget species; and (3) have deterioration and/or weathering characteristics that would make it break down rapidly to reduce its nontarget risk and environmental hazard. California's 2% Zn_3P_2 SRO bait meets many of these requirements: (1) it is efficacious in controlling vole damage in alfalfa (>94%); (2) dyed black Zn_3P_2 SRO groats were not acceptable to quail although accepted by pheasants; and (3) the Alcolec-S carrier provided bait deterioration characteristics that resulted in a short-term (~24 h) hazard to nontarget pheasants. Although the last finding is significant, the extent of the actual nontarget hazard to pheasants in the wild cannot always be confirmed or estimated from laboratory or enclosure studies that may present more of a worst case scenario than a representation of the real world hazard; therefore, research is underway to assess the potential hazard of the use of 2·0% Zn_3P_2 SRO groats to wild, free-ranging ring-necked pheasants following a typical CDFA vole control program in alfalfa. Additional study is also needed to determine the cause(s) of the critical change (i.e. toxicity, palatability, acceptability or other change) that corresponded with the highly significant reduction in pheasant survival during the initial 24 h period following bait application, but not observed thereafter. However, further field studies of the hazards to California quail from use of 2·0% Zn_3P_2 SRO groats in alfalfa do not appear to be warranted.

ACKNOWLEDGEMENTS

This work was supported by funds from CDFA (Contract no. 91-0514); research was conducted under USDA/APHIS Cooperative Agreements (12-34-74-0249-CA and 94-7455-0249-CA) with the Department of Fisheries and Wildlife, OSU, Corvallis, OR. We wish to thank the DWRC staff and students and faculty at OSU and Kathleen Fagerstone, Edward Schafer Jr and Mike Fall for reviewing this manuscript. Use of commercial or trade names does not constitute or imply endorsement by the Federal Government.

REFERENCES

American Veterinary Medical Association. (1993). Report of the AVMA Panel on Euthanasia. *J. Am. Vet. Med. Assoc.*, **202**(2), 229–249.

Andreev, S.B., Voevodin, A.V., Molchanour, V.A. & Khotyanovich, A.V. (1959). Some results on the use of tracer techniques in the study of plant protection. *Proc. United Nations International Conf. Peaceful Uses of Energy*, Geneva, Switzerland, Vol. 27, pp. 85–92.

Bennett, R.S., Edge, W.D., Griffis, W.L., Matz, A.C., Wolff, J.O. & Ganio, L.M. (1995). Temporal and spatial distribution of azinphos-methyl applied to alfalfa. *Arch. Environ. Contam. Toxicol.*, **27**, 534–540.

Breyl, I., Kredl, F., Holenda, J. & Fiala, J. (1973). Breakdown of zinc phosphide in bait compounds due to weather conditions. *Agrochemica*, **13**(11), 330–332.

California Department of Fish and Game (1962). Economic poisons (pesticides) investigations. California Department of Fish and Game, Wildlife Laboratory Job Completion Report, P-R Wildlife Restoration Project no. W-52-B-6, Sacramento, CA, 10 pp.

Chefurka, W., Kashi, K.P. & Bond, E.J. (1976). The effect of phosphine on electron transport in mitochondria. *Pesticide Biochem. Physiol.*, **6**, 65–84.

Dodge, W.E. (1967). Bio-telemetry — its use in vertebrate control studies. In: *Proc. 3rd Vertebr. Pest Conf.*, Vol. 3, pp. 126–127.

Doty, R.E. (1945). Rat control on Hawaiian sugar cane plantations. *Hawaiian Planters' Rec.*, **49**, 71–239.

Edge, W.D. & Manning, T.E. (1994). Demographic changes in enclosed gray-tailed vole (*Microtus canicaudus*) populations following a broadcast application of 2% zinc phosphide oat groats bait. Technical Report, Oregon State University (Cooperative Agreement no. 94-7455-0249-CA), Corvallis, OR, 99 pp.

Edge, W.D. & Wolff, J.O. (1993). Ecorisk Field Testing Research Plan. Department of Fisheries and Wildlife Study Plan, Oregon State University, Corvallis, OR, 26 pp.

Elmore, J.W. & Roth, F.J. (1943). Analysis and stability of zinc phosphide. *J. Assoc. Official Agric. Chem.*, **26**(4), 559–564.

Evans, J., Mass, R.D., Ellis, J.O., Griffith, R.E. Jr & Ward, A.L. (1966). Toxicants for controlling nutria in agricultural areas. United States Fish and Wildlife Service, Denver Wildlife Research Center Annual Progress Report, Work Unit F-39-2, Denver, CO, 10 pp.

Evans, J., Hegdal, P.L. & Griffith, R.E. (1970). Methods for controlling jackrabbits. *Proc. 4th Vertebr. Pest Conf.*, Vol. 4, pp. 109–116.

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (1988). The Federal Insecticide, Fungicide, and Rodenticide Act of 1947 as Amended. EPA 540/09-89-012, Federal Register, 53(86), 73 pp.

Fellows, D.P., Sugihara, R.T. & Pank, L.F. (1978). Evaluation of treatment techniques to control rats in macadamia nut orchards. United States Fish and Wildlife Service, Denver Wildlife Research Center, Denver, CO, 11 pp.

Glahn, J.F. & Lamper, L.D. (1983). Hazards to geese from exposure to zinc phosphide rodenticide baits. *Calif. Fish Game*, **69**, 105–114.

Gratz, N.G. (1973). A critical review of currently used single-dose rodenticides. *Bull. World Hlth Org.*, **48**, 469–477.

Hayne, D.W. (1951). Zinc phosphide: its toxicity to pheasants and effect of weathering upon its toxicity to mice. *Mich. Agric. Exp. Station Q. Bull.*, **33**(4), 412–425.

Hegdal, P.L. & Colvin, B.A. (1986). Radio-telemetry. In: *Inventory and Monitoring of Wildlife Habitat*, eds A.Y. Cooperrider, R.J. Boyd & H.R. Stuart. United States Department of Interior, United States Government Printing Office, Washington, DC, pp. 679–698.

Hegdal, P.L. & Gatz, T.A. (1977). Hazards to pheasants and cottontail rabbits associated with zinc phosphide baiting for microtine rodents in orchards. United States Fish and Wildlife Service, Denver, CO, 60 pp.

Henderson, F.R. & Boggess, E.K. (1979). 2% zinc phosphide for prairie dog control. Kansas State University Cooperative Extension Service, AF-29, 4 pp.

Hilton, H.W., Robison, W.H., Teshima, A.H. & Nass, R.D. (1972). Zinc phosphide as a rodenticide for rats in Hawaiian sugarcane. *Proc. 14th International Society of Sugarcane Technologists*, Vol. 14, pp. 561–570.

Hines, T. & Dimmick, R.W. (1970). The acceptance by bobwhite quail of rodent baits dyed and treated with zinc phosphide. *Proc. Annual Conf. Southeastern Association of Game and Fish Commissioners*, Vol. 24, pp. 201–205.

Hood, G.A. (1972). Zinc phosphide — a new look at an old rodenticide for field rodents. In: *Proc. 5th Vertebr. Pest Conf.*, Vol. 5, pp. 85–92.

Hudson, R.H., Tucker, R.K. & Haegele, M.A. (1984). *Handbook of Toxicity of Pesticides to Wildlife*. United States Department of Interior, Fish and Wildlife Service, Research Publication no. 153, Washington, DC, 90 pp.

Janda, J. & Bosseova, M. (1970). The toxic effect of zinc phosphide baits on partridges and pheasants. *J. Wildlife Mgmt.*, **34,** 220–223.

Johnson, G.D. & Fagerstone, K.A. (1994). Primary and secondary hazards of zinc phosphide to nontarget wildlife — a review of the literature. United States Department of Agriculture/Animal and Plant Health Inspection Service/Denver Wildlife Research Center, Report no. 11-55-005, Denver, CO, 26 pp.

Koehler, A.E., Tobin, M.E., Goodall, M.J. & Sugihara, R. (1995). Weatherability of selected commercial zinc phosphide rodent baits. *Int. Biodeter. Biodeg.*, (in press).

Lewis, S.R. & O'Brien, J.M. (1990). Survey of rodent and rabbit damage to alfalfa hay in Nevada. In: *Proc. 14th Vertebr. Pest Conf.*, Vol. 14, pp. 116–119.

Littrell, E.E. (1990). Effects of field vertebrate pest control on nontarget wildlife (with emphasis on bird and rodent control). In: *Proc. 14th Vertebr. Pest Conf.*, Vol. 14, pp. 59–61.

Marsh, R.E. (1988). Relevant characteristics of zinc phosphide as a rodenticide. In: *Great Plains Wildlife Damage Control Proc.*, Vol. 8, pp. 70–74.

Mech, L.D. (1983). *Handbook of Animal Radio-tracking*. University of Minnesota Press, Minneapolis, MN, 107 pp.

Pank, L.F. (1976). Effects of bait formulations on toxicant doses and efficacy. In: *Proc. 7th Vertebr. Pest Conf.*, Vol. 7, pp. 196–202.

Ramey, C.A., Schafer, E.W. Jr, Fagerstone, K.A. & Palmateer, S.D. (1994). Active ingredients in APHIS's vertebrate pesticides — use and reregistration status. In: *Proc. 16th Vertebr. Pest Conf.*, Vol. 16, pp. 124–132.

SAS Institute (1987). *SAS/STAT Guide for Personal Computers*. SAS Institute, Inc., Cary, North Carolina, pp. 125–154.

Savarie, P.J. (1981). The nature, modes of action, and toxicity of rodenticides. In: *CRC Handbook of Pest Management in Agriculture*, Vol. III, ed. D. Pimentel. CRC Press, Boca Raton. FL, pp. 113–127.

Sterner, R.T. & Ramey, C.A. (1995). Deterioration of lecithin-adhered zinc phosphide baits in alfalfa. *Int. Biodeter. Biodeg.* (in press).

Sterner, R.T., Ramey, C.A., Edgc, W.D., Manning, T.E. & Wolff, J.O. (1994). Broadcast application of 2% zinc phosphide steam rolled oat groats to control gray-tailed voles in alfalfa: an enclosure-type efficacy study. United States Department of Agriculture/Animal Plant Health Inspection Service, Denver Wildlife Research Center, Denver, CO, 876 pp.

Tietjen, H.P. & Matschke, G.H. (1982). Aerial prebaiting for management of prairie dogs with zinc phosphide. *J. Wildlife Mgmt*, **46**(4), 1108–1112.

Zbirovsky, L. & Myska, J. (1957). *Insekticidy, Fungicidy, Rodenticidy.* Nakladatelstvi CSAV, Praha.